621.365
I&655te
no.13-16
cop.3

Q.

21.365
l655 te
o. 15
op. 3

ENGINEERING LIBRARY

ANTENNA LABORATORY

Technical Report No. 15

DISTRIBUTED COUPLING
TO
SURFACE WAVE ANTENNAS

by

Ralph Richard Hodges, Jr.

5 January 1957

Contract No. AF33(616)-3220
Project No. 6(7-4600) Task 40572
WRIGHT AIR DEVELOPMENT CENTER

ELECTRICAL ENGINEERING RESEARCH LABORATORY
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS

Antenna Laboratory

Technical Report No. 15

DISTRIBUTED COUPLING
TO
SURFACE WAVE ANTENNAS

by

Ralph Richard Hodges, Jr.

5 January 1957

Contract AF33(616)-3220
Project No. 6(7-4600) Task 40572
WRIGHT AIR DEVELOPMENT CENTER

Electrical Engineering Research Laboratory
Engineering Experiment Station
University of Illinois
Urbana, Illinois

Digitized by the Internet Archive
in 2013

http://archive.org/details/distributedcoupl15hodg

621.365
I l 6s5te
no. 15
cop. 3

CONTENTS

Page

Acknowledgement vi

Abstract vii

1. Introduction 1

2. Experimental Procedure and Presentation of Results 3

    2.1 Outline of the Problem 3
    2.2 Propagation Properties of the Waveguides 3
    2.3 Input to Output Attenuation of the Exciting Waveguide 5
    2.4 Aperture Distributions 8
    2.5 Radiation Patterns 18

3. Conclusions 25

4. Bibliography 25

ILLUSTRATIONS

Figure Number *Page*

1. Axially Excited Traveling Wave Slot Antenna 2
2. c/v versus Frequency for the Radiating Guide with and without Coupling (Experimental) and for the Exciting Waveguide (Calculated) 4
3. Electric Field Amplitude Distribution in an End Fed Radiating Guide With Z_0 Termination for 8300 to 8700 Megacycles 4
4. Cross-Section of Coupled Waveguides 5
5. Cut-Away View of Variable Length of Coupling Apparatus 6
6. Equipment for Exciting Guide Attenuation Measurement 7
7. a-e Attenuation in the Exciting Waveguide versus Length of Coupling Region for 1/4, 9/32 and 5/16 Inch Diameter Coupling Holes, from 8800 to 10,200 Megacycles 9-13
8. Attenuation in the Exciting Waveguide versus Length of Coupling Region for 10,100 Megacycles 14
9. Aperture Amplitude Distribution for 40 Inches of Coupling at 10,100 Megacycles 14
10. Aperture Amplitude Distribution for 28 Inches of Coupling at 10,100 Megacycles 15
11. Aperture Amplitude Distribution for 25 Inches of Coupling at 10,100 Megacycles 15
12. Attenuation in the Exciting Waveguide versus Length of Coupling Region for 9,700 Megacycles 16
13. Aperture Amplitude Distributions for 4 and 8 Inches of Coupling at 9700 Megacycles 16
14. Attenuation in the Exciting Waveguide versus Length of Coupling Region for 9100 Megacycles 17
15. Aperture Amplitude Distributions for 40 and 28 Inches of Coupling at 9100 Megacycles 17
16. Patterns for Selected Lengths of Coupling for 9100 Megacycles 19
17. Patterns for Selected Lengths of Coupling for 9200 Megacycles 20

ILLUSTRATIONS (continued)

Figure Number *Page*

18. Patterns for Selected Lengths of Coupling for 9300 Megacycles 21

19. Patterns for Selected Lengths of Coupling for 9400 Megacycles 22

20. Patterns for Selected Lengths of Coupling for 9500 Megacycles 23

ACKNOWLEDGMENT

The author is indebted to V.H. Rumsey and W.L. Weeks for their assistance and guidance, and to J. Kemp, W. Hartley, and J. Stafford, who made most of the measurements.

ABSTRACT

This investigation concerns the excitation of a traveling wave in a dielectric filled rectangular channel in an infinite ground plane, by means of distributed coupling to a closed waveguide. The data show some of the effects of the size of the coupling holes and the length of the coupling region upon 1) the attenuation between the input and output of the exciting waveguide, 2) the aperture distribution, and 3) the radiation pattern, for various frequencies.

1. INTRODUCTION

The axially excited traveling wave slot antenna described by Royal[1] consists of a radiating waveguide coupled to an exciting waveguide. The radiating waveguide is a rectangular, dielectric filled channel in an infinite ground plane. The exciting waveguide is partially dielectric filled to give a phase velocity equal to that of the radiating waveguide. The coupling mechanism is a series of holes along the axis of the guides, in their common wall. (See Figure 1)

This investigation concerns the effects of the phase velocities and of the coupling length on the waves excited in the radiating guide. The principal interest is centered around the fact that the radiating guide can propagate many modes. For the case of closed waveguides, Miller has shown that energy can be coupled from a single mode guide to a selected mode of a multi-mode structure by proper choice of the coupling mechanism and of the phase velocities.[2] The extent of this effect for an open waveguide is one of the main points of this investigation.

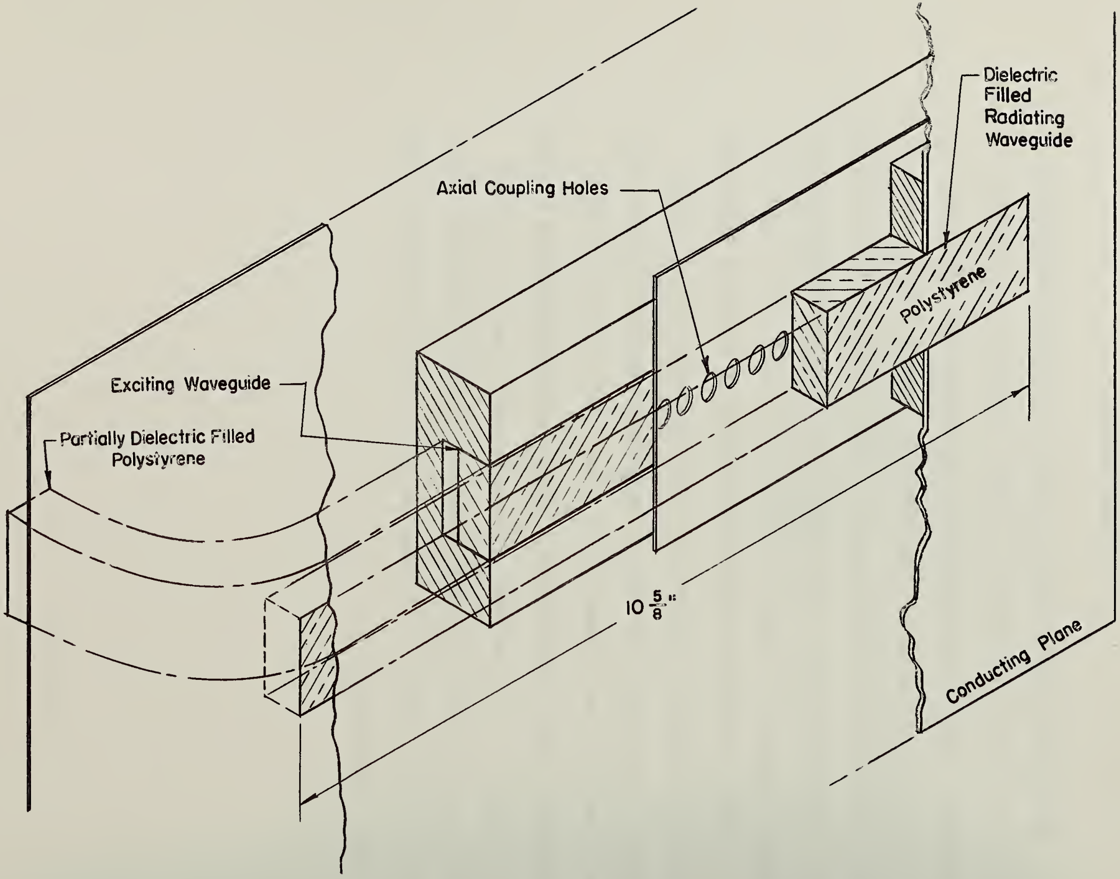


Figure I Axially Excited Traveling Wave Slot Antenna

2. EXPERIMENTAL PROCEDURE AND PRESENTATION OF RESULTS

2.1 Outline of the Problem

A previous investigation of the antenna in Figure 1 had shown that energy was transferred periodically from guide to guide as the length of the coupling region was increased. This investigation was limited to a relatively short antenna and was hampered by the presence of reflected waves in the radiating waveguide due to its abrupt ends. These findings suggested that similar measurements be made on an antenna which would have a maximum coupling length sufficient to show several cycles of power transfer. These measurements include the attentuation of the exciting guide, the aperture distribution, and the radiation pattern for various lengths of coupling.

2.2 Propagation Properties of the Waveguides

The cross sectional dimensions of waveguides used in this experiment are shown in Figure 4. They are identical in cross section to their counterparts in Figure 1.

Figure 2 shows the relative phase velocity, c/v, as a function of frequency for the radiating guide in a region of 5/16 inch diameter coupling holes and in a region of no coupling. A calculated curve of the relative phase velocity of the exciting guide is also presented. It can be seen that the rate of change of phase velocity of the exciting guide is considerably different from that of the radiating guide. This allows the effects of the difference in phase velocities to be investigated.

The attenuation of the radiating guide is very small until the frequency reaches the point where c/v becomes less than unity. The

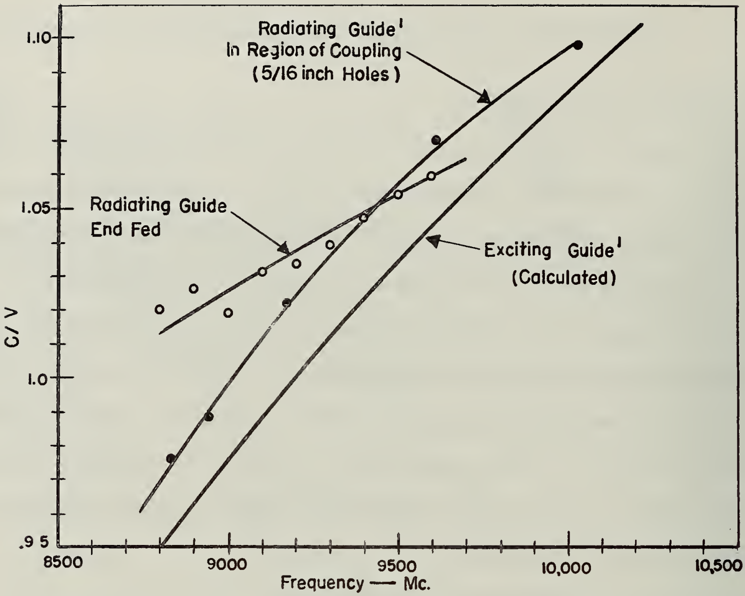


Figure 2 c/v vs Frequency for the Radiating Guide with and without Coupling (Experimental) and for the Exciting Waveguide (Calculated)

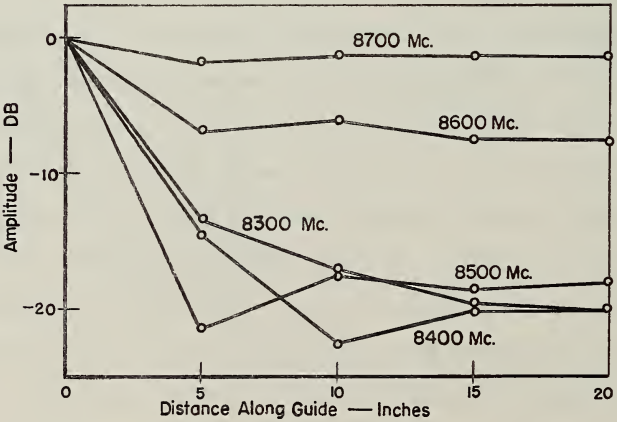


Figure 3 Electric Field Amplitude Distribution
(End Fed Radiating Guide - Terminated)
8300-8700 mc

curves of Figure 3 show that the attenuation becomes large for frequencies lower than 8600 megacycles.

2.3 Input to Output Attenuation of the Exciting Waveguide

The coupling mechanism used in this part of the investigation is a thin strip of phosphor bronze which has holes punched along a portion of its axis to serve as coupling apertures. This strip serves as the common wall for the two guides (See Figure 4) and can be moved along its axial direction to vary the length of the region of coupling from zero to 40 inches. Coupling apertures of 1/4, 9/32, and 5/16 inch diameters spaced 23/64 inch center to center are investigated. Figures 5 and 6 show this apparatus and the other components used in the measurement.

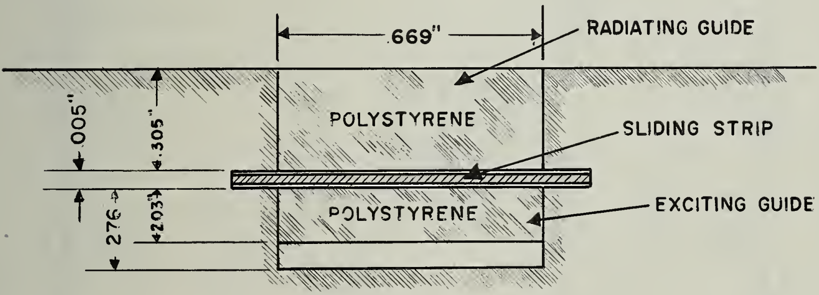


Figure 4 Cross Section of Coupled Waveguides
(not to scale)

The attenuation of the exciting guide is defined as the ratio of its output power to its input power. The slide screw tuner (See Figure 6) is adjusted to match the line where the 20 db coupler is located. The coupler gives a reference signal which is proportional to the input power.

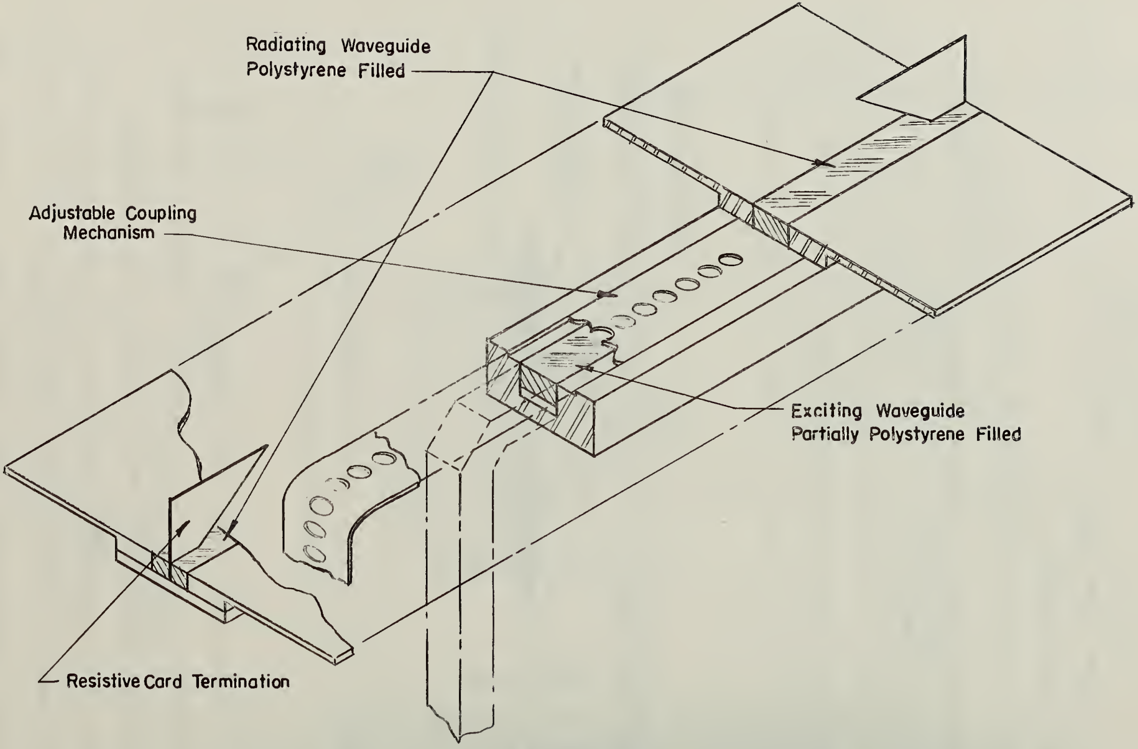


Figure 5 Cut-Away View of Variable Length of Coupling Apparatus

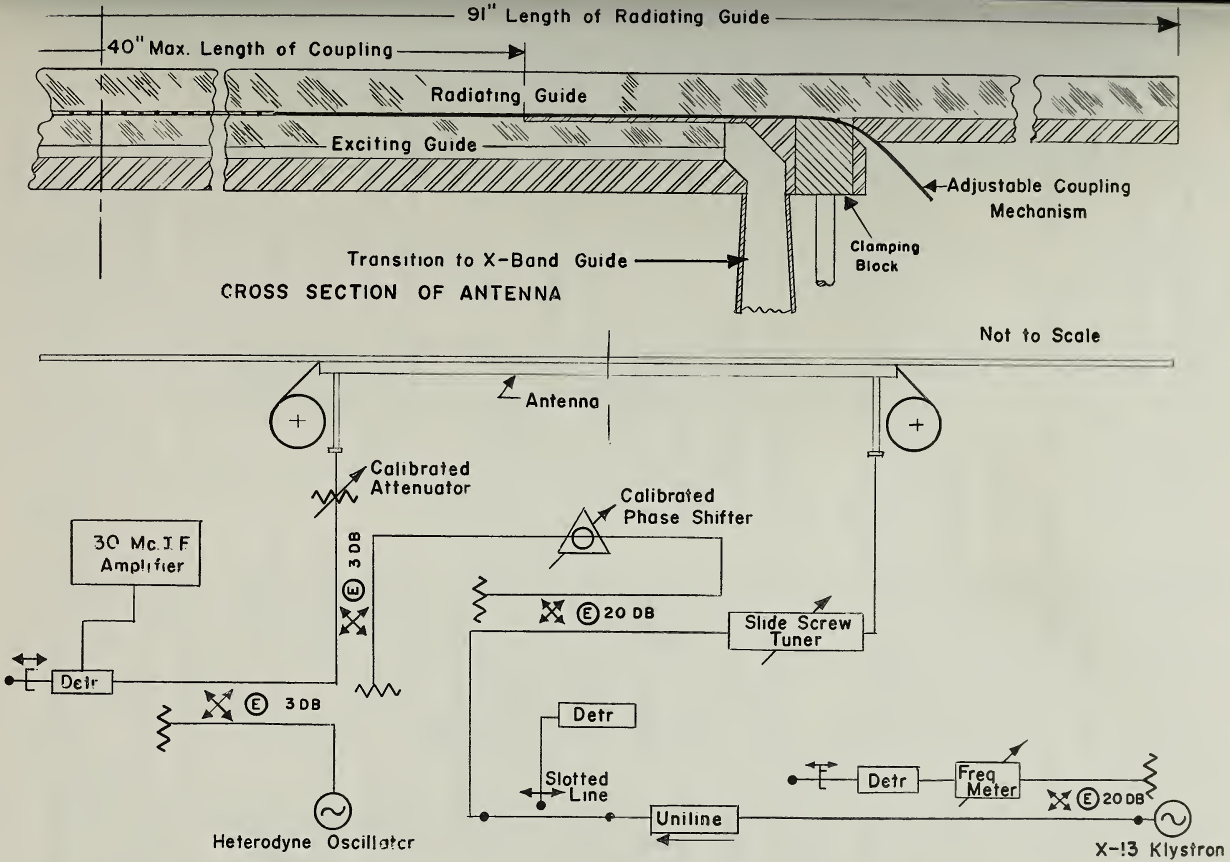


Figure 6 Equipment for Exciting Guide Attenuation Measurement

The phase of this reference signal is shifted and the output power is attenuated to give a null indication at the I.F. amplifier output. The attenuation is then the difference between the readings of the attenuator obtained in this way and those obtained when the antenna is replaced with a section of lossless x-band waveguide.

The results are presented graphically in Figure 7 (a to e). They are plotted so that for any frequency, the attenuation of the exciting guide, as a function of length of coupling, can be compared for three sizes of coupling holes.

It is obvious from the irregular shape of the attenuation curves that many modes are being excited in the radiating waveguide. It is interesting to note the curves for the 5/16 inch diameter holes in the frequency range of 9,400 to 9,900 megacycles. A null at 22 inches of coupling for 9,400 mc has disappeared at 9,600 mc and, at 9,800 mc, nulls appear at 13 and 27 inches of coupling. The same thing occurs in the vicinity of 10,100 mc for the 9/32 inch diameter hole coupling mechanism.

2.4 Aperture Distributions

Figures 8 to 15 show the results of an investigation of the aperture distribution for various lengths of coupling. For these measurements the radiating guide has reflectionless terminations at each end, as in Section 2.3. Figures 8, 12, and 14 are the attenuation curves (from Section 2.3) for 10,100 mc, 9,700 mc, and 9,100 mc, respectively. The others show the aperture distribution of normal electric field at these frequencies for various lengths of coupling. It is interesting to note from the graphs of this section that the points of maximum and minimum electric field correspond to the maximum and minimum points on the

Figure 7-a Attenuation in the Exciting Waveguide in DB Versus Length of Coupling Region in Inches

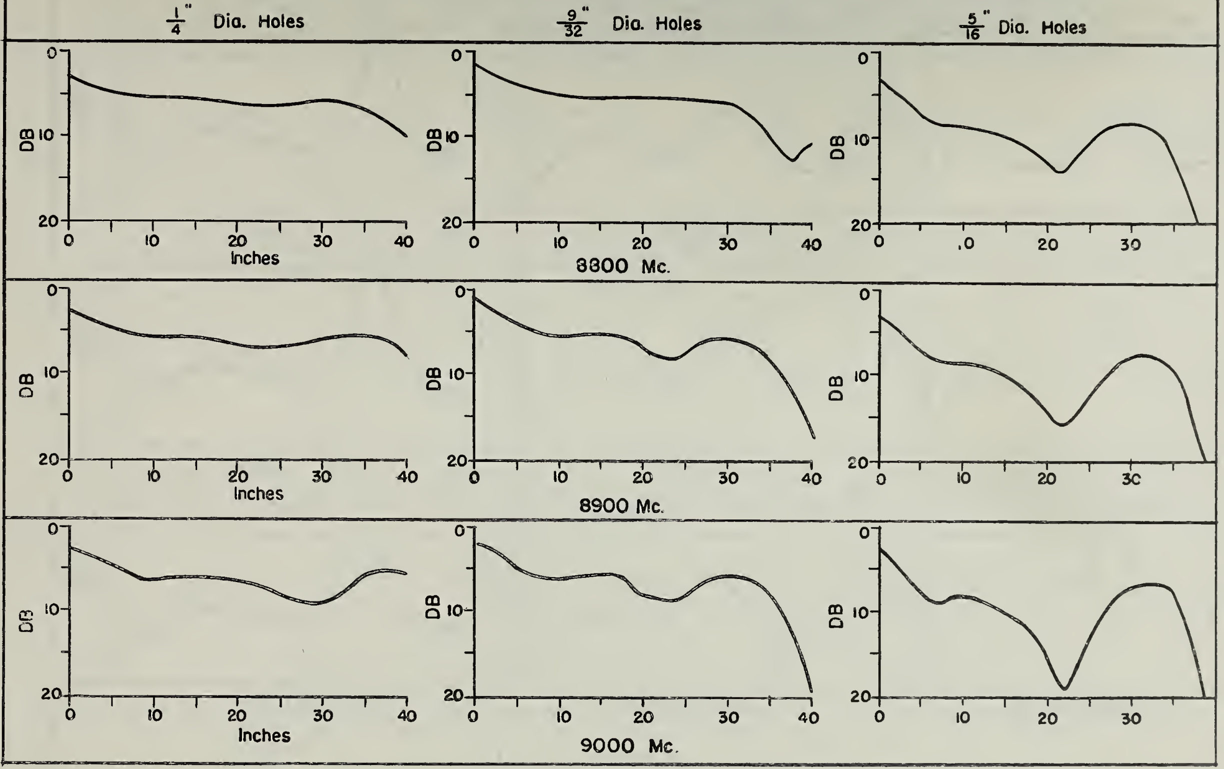


Figure 7-b Attenuation in the Exciting Waveguide in DB Versus Length of Coupling Region in Inches

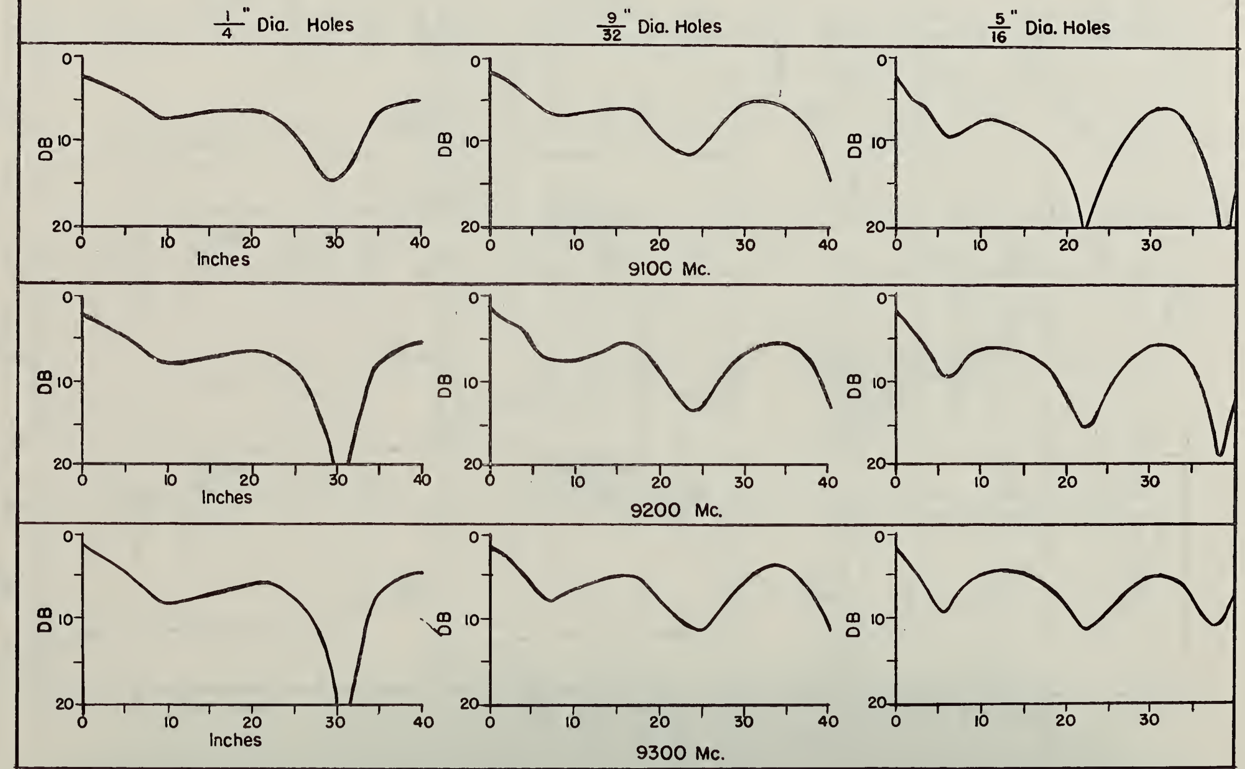
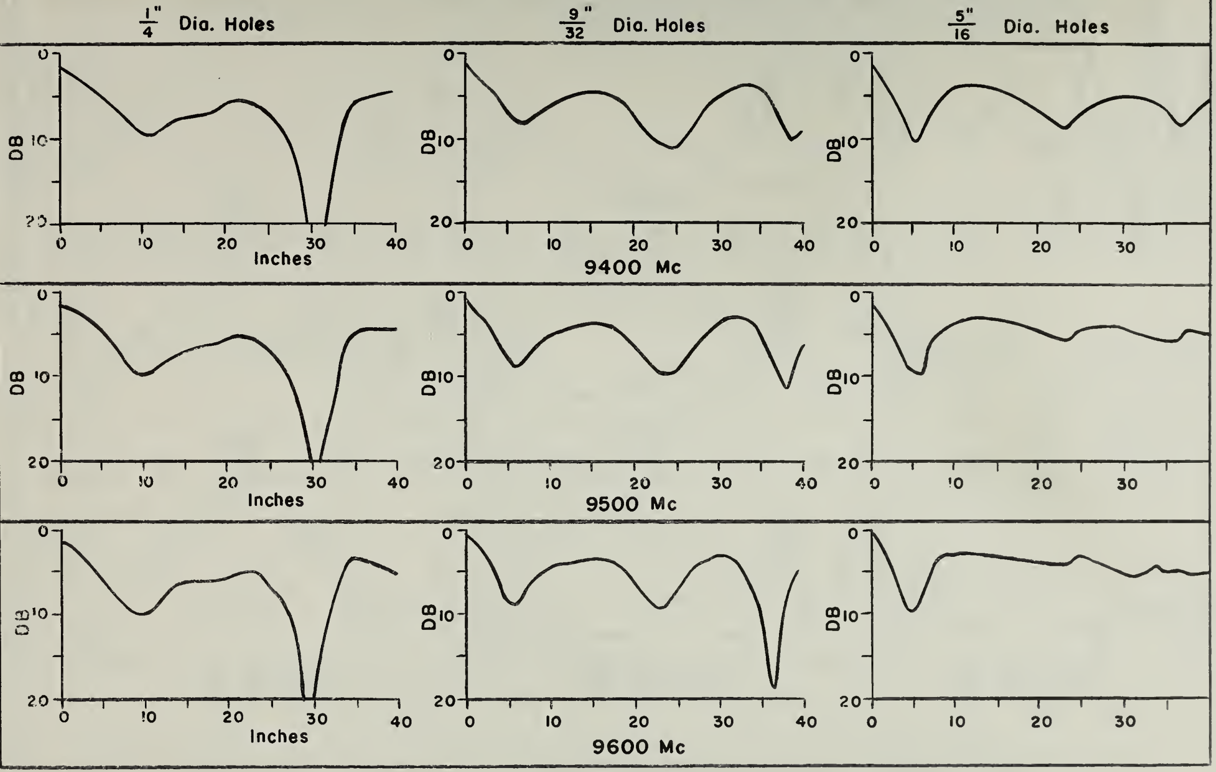


Figure 7-c Attenuation in the Exciting Waveguide in DB Versus Length of Coupling Region in Inches



UNIVERSITY OF ILLINOIS
LIBRARY

Figure 7-d Attenuation in the Exciting Waveguide in DB Versus Length of Coupling Region in Inches

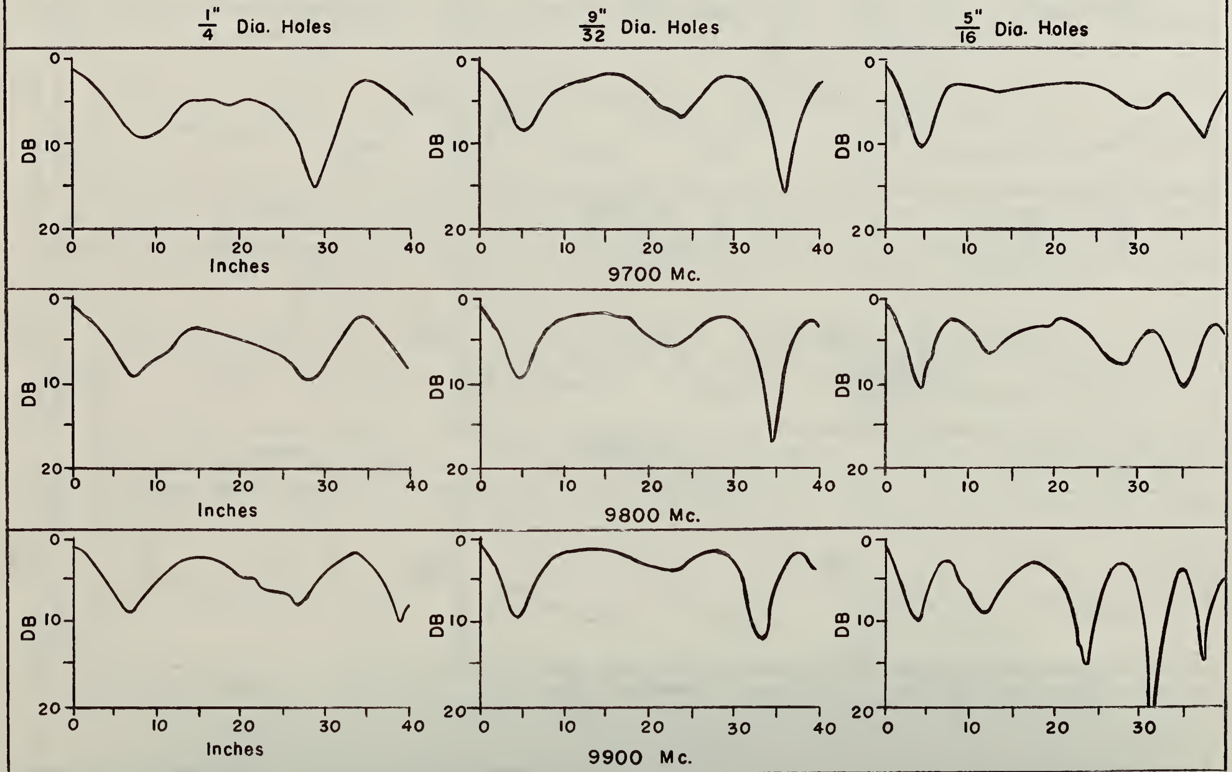
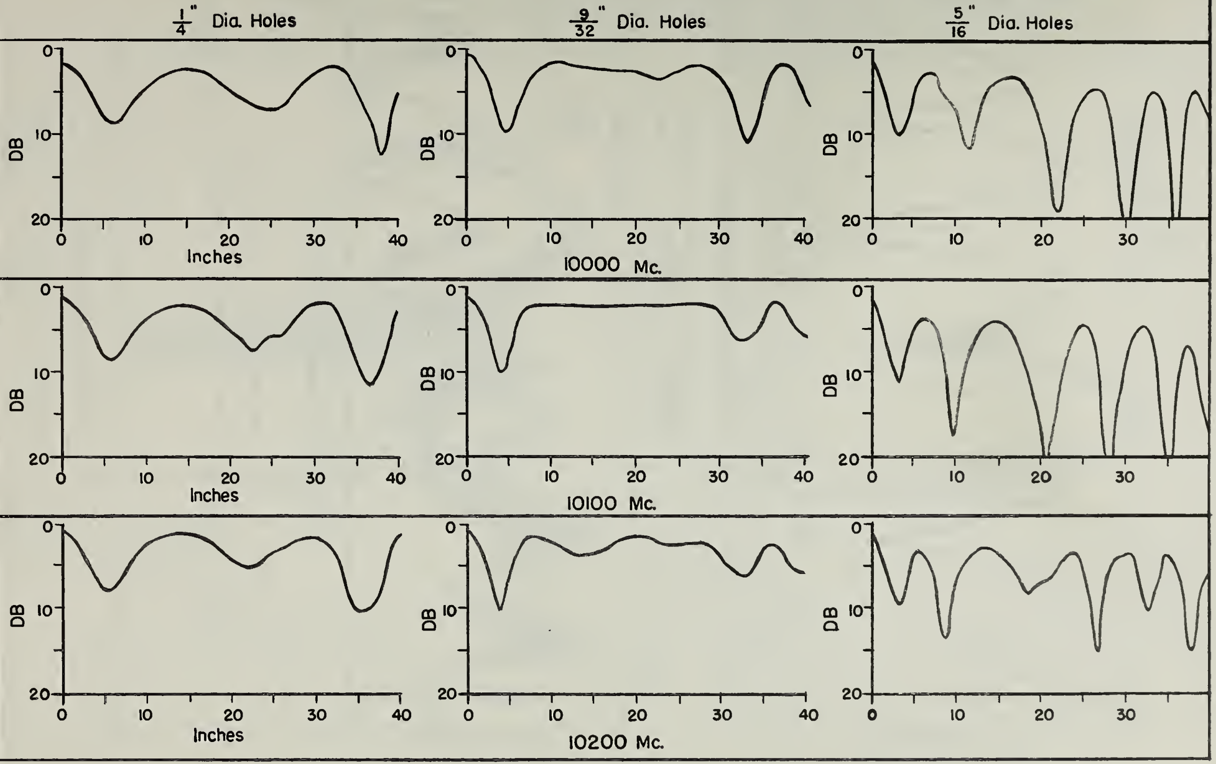


Figure 7-e Attenuation in the Exciting Waveguide in DB Versus Length of Coupling Region in Inches



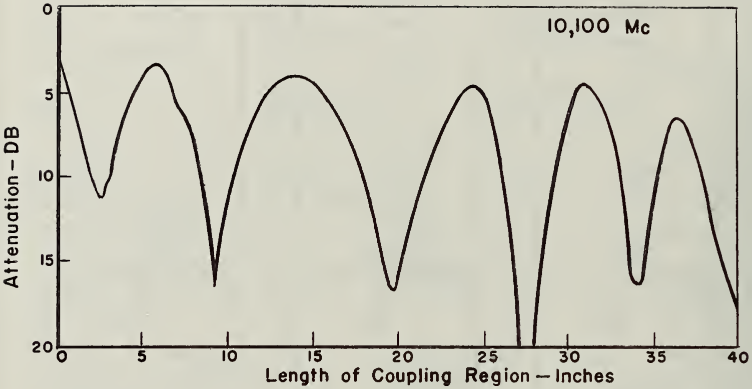


Figure 8 Attenuation in Exciting Guide versus Length of Coupling Region

Frequency = 10,100 mc

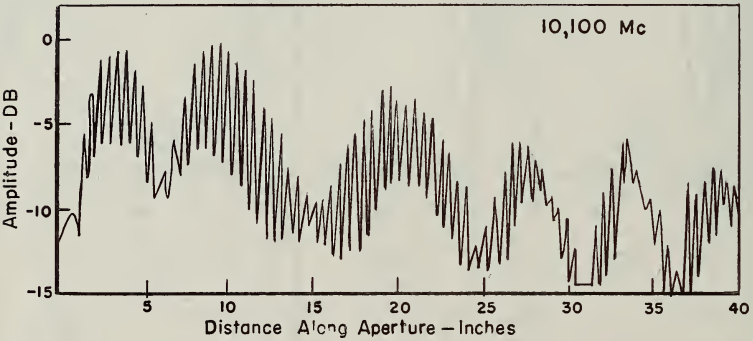


Figure 9 Aperture Amplitude Distribution

(Frequency = 10,100 mc., Length of Coupling = 40 inches)

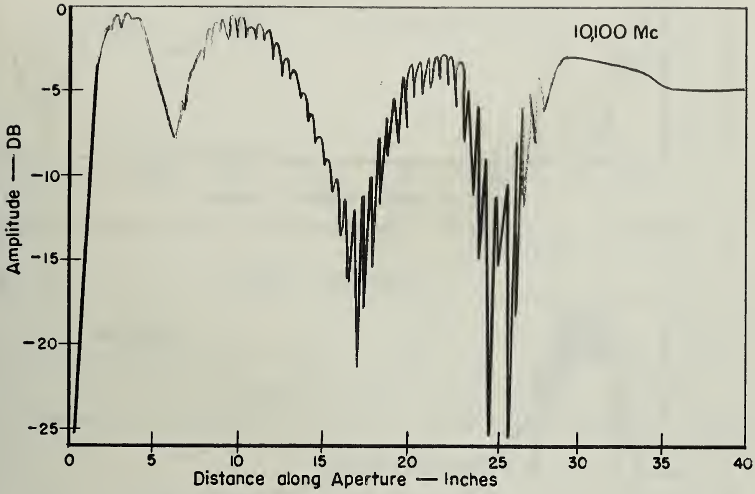


Figure 10 Aperture Amplitude Distribution
Frequency = 10,100 mc. Length of Coupling = 28 inches

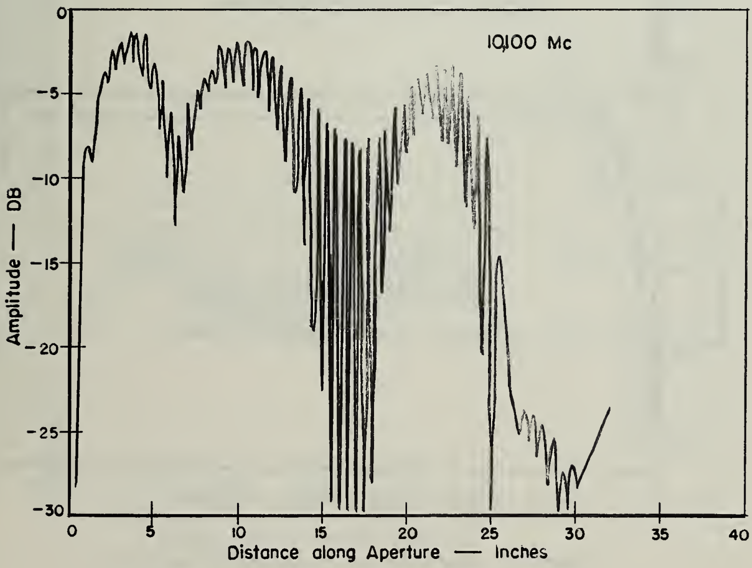


Figure 11 Aperture Amplitude Distribution
(Frequency = 10,100 mc, Length of Coupling = 25 inches)

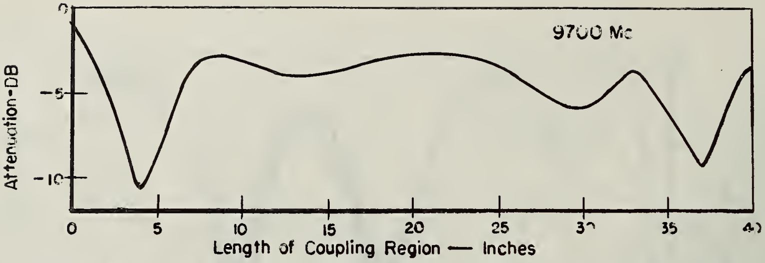


Figure 12 Attenuation in Exciting Guide versus Length of Coupling Region

(Frequency = 9700)

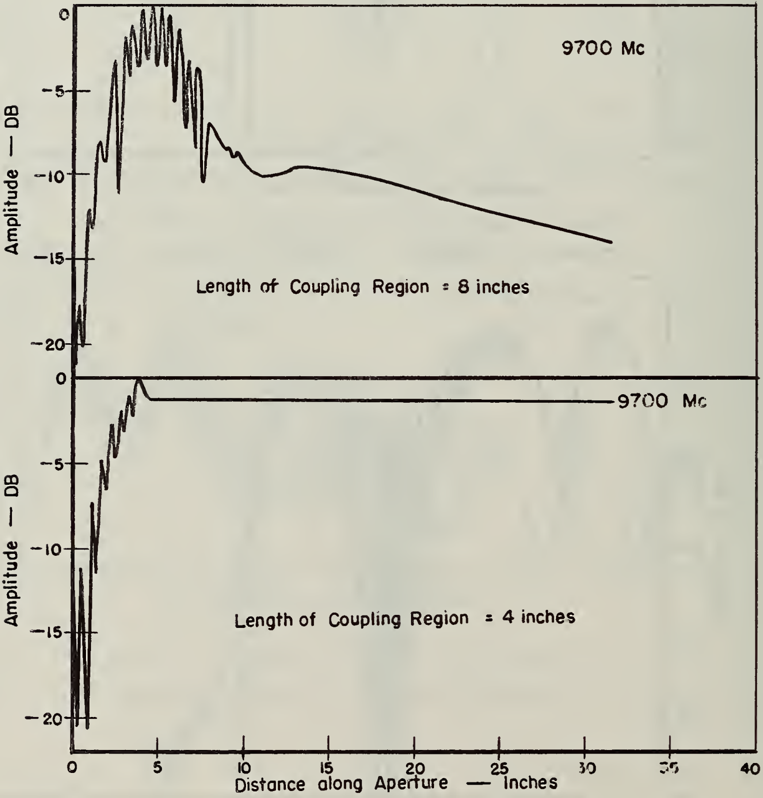


Figure 13 Aperture Amplitude Distributions

(Frequency = 9700 mc)

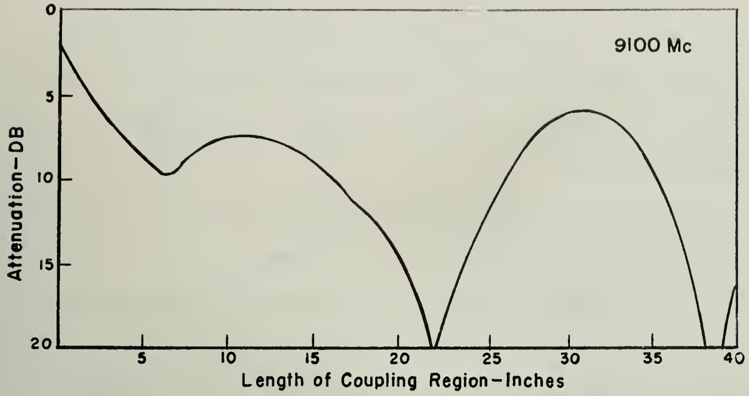


Figure 14 Attenuation in Exciting Guide versus Length of Coupling Region
(Frequency = 9100 mc)

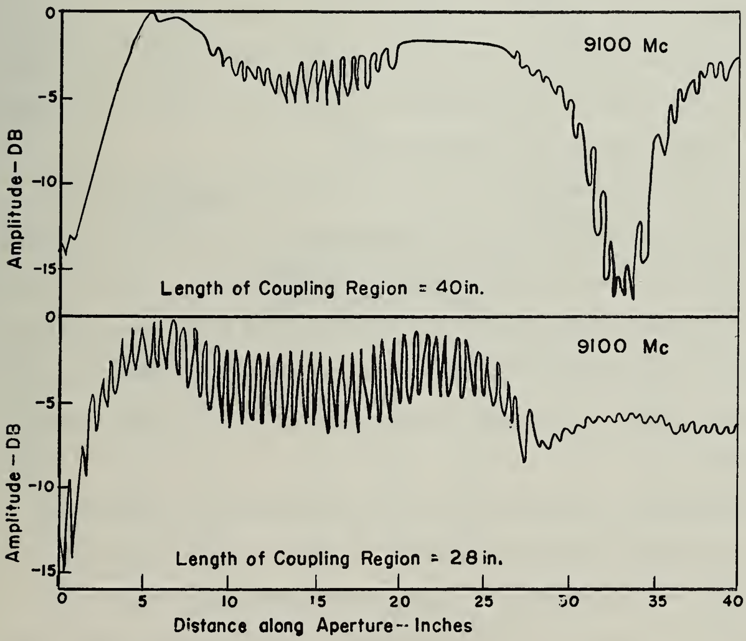


Figure 15 Aperture Amplitude Distributions
(Frequency = 9100 mc)

attenuation curves. Also note that the standing wave present in the radiating guide when the length of coupling corresponds to a minimum of attenuation is larger than when it corresponds to a maximum.

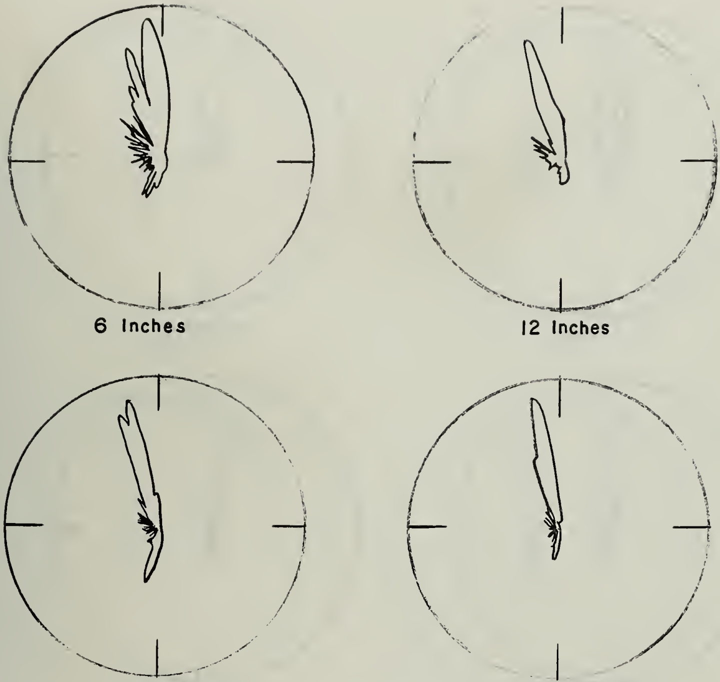
2.5 Radiation Patterns

The study of radiation patterns is made with an antenna similar to the one shown in Figure 1, except that the radiating waveguide is 32 5/8 inches long. The coupling mechanism is a series of 5/16 inch diameter holes spaced 23/64 inch (same as in Sections 2.3 and 2.4). Figures 16 to 20 show the radiation patterns corresponding to various lengths of coupling over the frequency range of 9,100 mc to 9,500 mc. An attenuation curve (from Section 2.3) is also shown for each frequency.

An examination of the major lobes of these patterns indicates that selective excitation of approximately a single mode is possible by proper choice of the length of the coupling region.

From the patterns for 12 inches of coupling it appears that, as frequency increases, the major lobe begins to split, as if the excitation of a second mode increases as frequency increases, in this range. The presence of this strong second mode was pointed out in Section 2.3 from examination of the attenuation curves in this frequency range. Also, as frequency increases, the patterns show a decrease in the front to back lobe ratio.

Another point of interest is that Royal theoretically determined that a cosinusoidal distribution of normal electric dipoles along the axis of the aperture would give a good end-fire pattern.[1] The measurement of electric field in the aperture in Section 2.4 shows that a good approximation to this distribution is obtained when the length



6 Inches   12 Inches

17 Inches   22 Inches

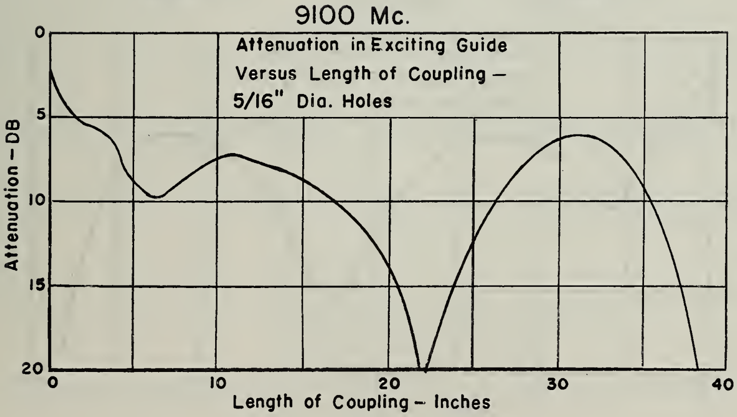
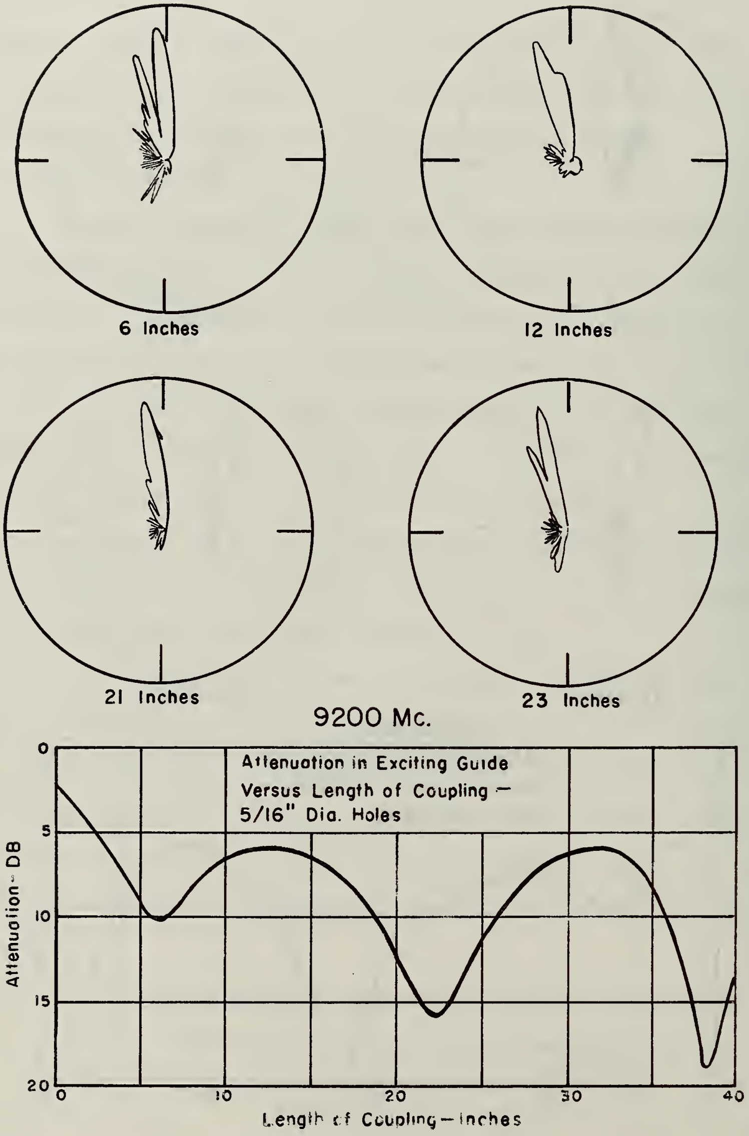


Figure 16 Patterns for Selected Lengths of Coupling


6 Inches

12 Inches

21 Inches

23 Inches

9200 Mc.

Figure 17 Patterns for Selected Lengths of Coupling

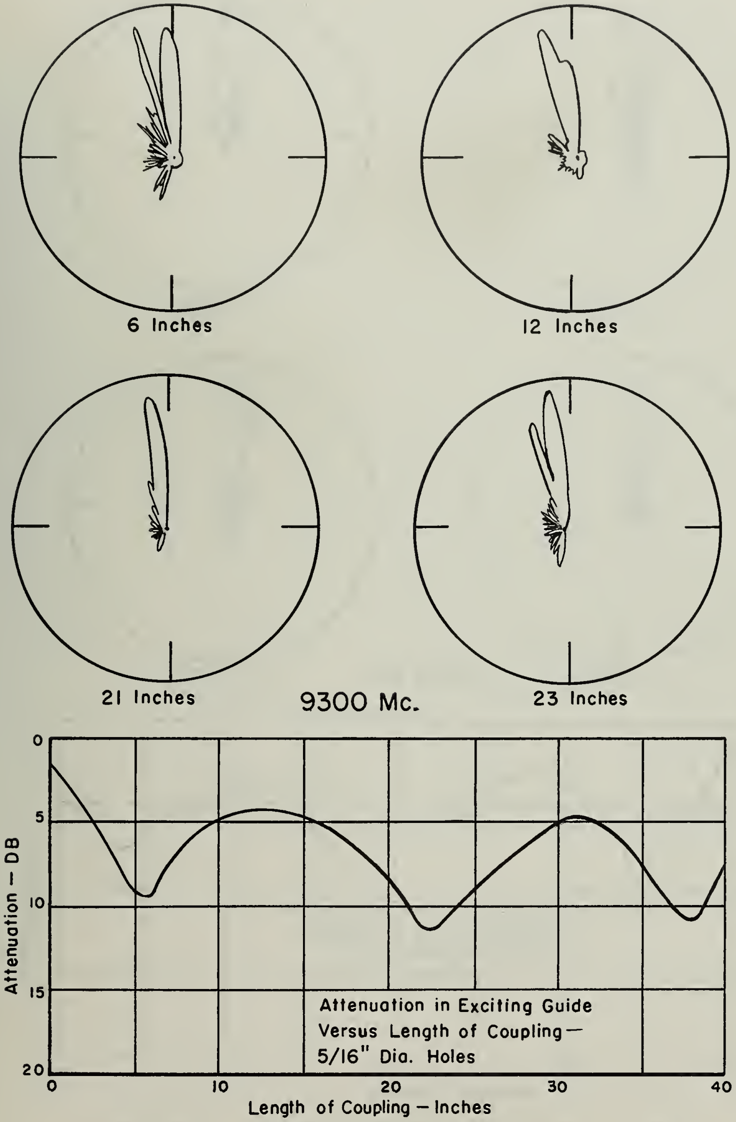
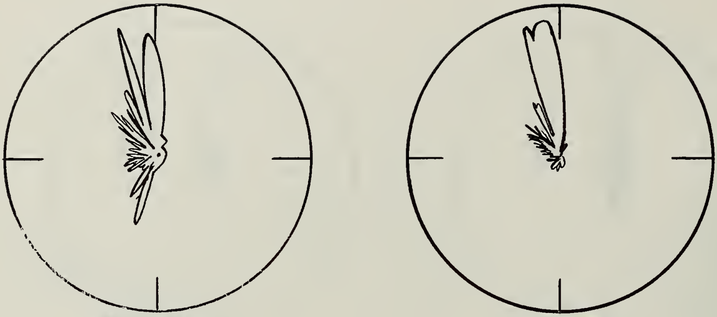
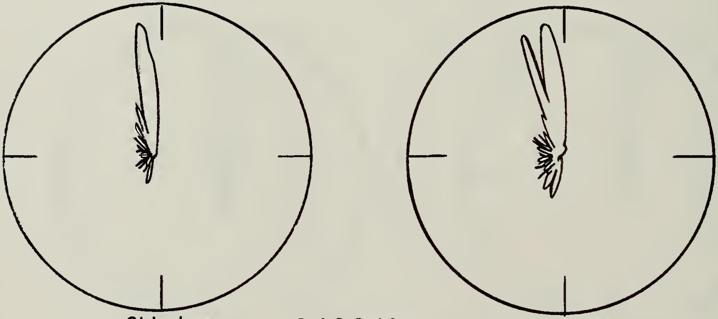


Figure 18 Patterns for Selected Lengths of Coupling



5 Inches

17 Inches



21 Inches

9400 Mc.

23 Inches

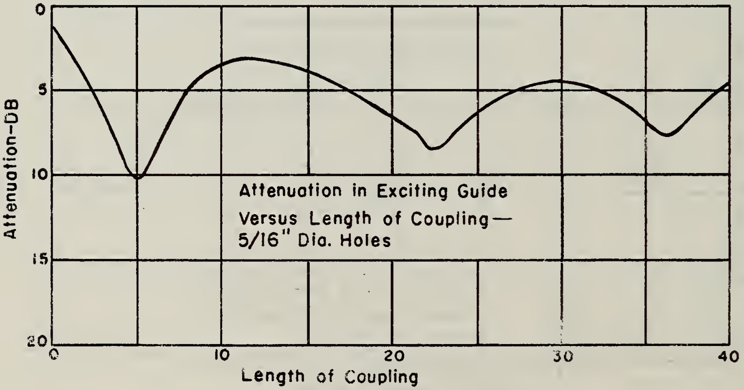
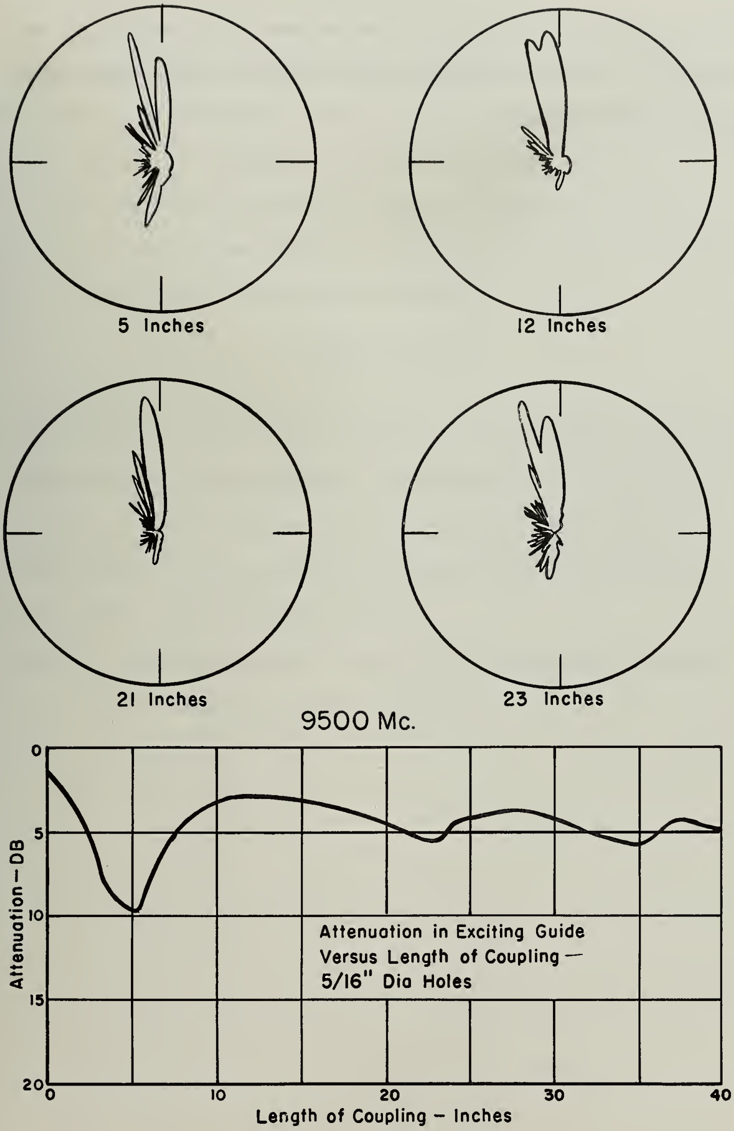


Figure 19 Patterns for Selected Lengths of Coupling



5 Inches

12 Inches

21 Inches

23 Inches

Figure 20 Patterns for Selected Lengths of Coupling

of coupling is the same as for the first minimum of attenuation in the exciting guide. For the frequency range of these patterns, this length is approximately 12 inches.

3. CONCLUSIONS

It is shown that the mode purity and amplitude distribution of the fields in the radiating waveguide of the axially excited traveling wave slot antenna are dependent upon the guide phase velocities, the size of the coupling holes, and the length of the coupling region. It is also shown that a good end-fire pattern can be obtained by proper choice of the length of the region of coupling.

4. BIBLIOGRAPHY

1. Royal, D.E., "Axially Excited Surface Wave Antennas, "Technical Report No. 7, Antenna Section, Electrical Engineering Research Laboratory, University of Illinois; prepared under Contract AF33(616)-310 with Air Materiel Command, Wright-Patterson Air Force Base, Ohio; 10 October 1955.
2. Miller, S.E., "Coupled Wave Theory and Waveguide Applications," *Bell System Technical Journal,* May 1954.

DISTRIBUTION LIST FOR REPORTS ISSUED UNDER CONTRACT AF33(616)-3220

One copy each unless otherwise indicated

Commander
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

Attn: Mr. E.M. Turner, WCLRS-6
4 copies

Commander
Wright Air Development Center
Wright-Patterson Air Force Base, Ohio

Attn: Mr. N. Draganjac, WCLNT-4

Armed Services Technical Information
Knott Building Agency
4th and Main Streets 5 copies
Dayton 2, Ohio 1 repro

Attn: DSC-SA (Reference AFR205-43)

Commander
Hq. A.F. Cambridge Research Center
Air Research and Development Command
Laurence G. Hanscom Field
Bedford, Massachusetts

Commander
Hq. A.F. Cambridge Research Center
Air Research and Development Command
Laurence G. Hanscom Field
Bedford, Massachusetts

Attn: CRTOTL-1

Commander
Hq. A.F. Cambridge Research Center
Air Research and Development Command
Laurence G. Hanscom Field
Bedford, Massachusetts

Attn: CRRD, R.E. Hiatt

Air Force Development Field
Representative
Attn: Capt. Carl B. Ausfahl
Code 1010
Naval Research Laboratory
Washington 25, D.C.

Director
Ballistics Research Lab.
Aberdeen Proving Ground, Maryland

Attn: Ballistics Measurement Lab.

Office of the Chief Signal Officer
Attn: SIGNET-5
Eng. & Technical Division
Washington 25, D.C.

Commander
Rome Air Development Center
Attn: RCERA-1, D. Mather
Griffiss Air Force Base
Rome, New York

Director
Evans Signal Laboratory
Belmar, New Jersey

Attn: Mr. O.C. Woodyard

Director
Evans Signal Laboratory
Belmar, New Jersey

Attn: Mr. S. Krevsky

Director
Evans Signal Laboratory
Belmar, New Jersey

Attn: Technical Document Center

Naval Air Missile Test Center
Point Mugu, California

Attn: Antenna Section

Commander
U.S. Naval Air Test Center
Attn: ET-315
Antenna Section
Patuxent River, Maryland

DISTRIBUTION LIST (Cont.)

Commander
Air Force Missile Test Center
Patrick Air Force Base, Florida

Attn: Technical Library

Chief
BuShips, Room 3345
Department of the Navy
Attn: Mr. A.W. Andrews
Code 883
Washington 25, D.C.

Director
Naval Research Laboratory
Attn: Dr. J.I. Bohnert
Anocostia
Washington 25, D.C.

National Bureau of Standards
Department of Commerce
Attn: Dr. A.G. McNish
Washington 25, D.C.

Director
U.S. Navy Electronics Lab.
Attn: Dr. T.J. Keary
Code 230
Point Loma
San Diego 52, California

Chief of Naval Research
Department of the Navy
Attn: Mr. Harry Harrison
Code 427, Room 2604
Bldg. T-3
Washington 25, D.C.

Airborne Instruments Lab., Inc.
Attn: Dr. E.G. Fubini
Antenna Section
160 Old Country Road
Mineola, New York
M/F Contract AF33(616)-2143

Andrew Alford Consulting Engrs.
Attn: Dr. A. Alford
299 Atlantic Ave.
Boston 10, Massachusetts
M/F Contract AF33(038)-23700

Chief
Bureau of Aeronautics
Department of the Navy
Attn: W.L. May, Aer-EL-4114
Washington 25, D.C.

Chance-Vought Aircraft Division
United Aircraft Corporation
Attn: Mr. F.N. Kickerman
Thru: BuAer Representative
Dallas, Texas

Consolidated-Vultee Aircraft Corp.
Attn: Mr. R. E. Honer
San Diego Division
San Diego 12, California
M/F Contract AF33(600)-26530

Consolidated-Vultee Aircraft Corp.
Fort Worth Division
Attn: C.R. Curnutt
Fort Worth, Texas
M/F Contract AF33(038)-21117

Textron American, Inc. Div.
Dalmo Victor Company
Attn: Mr. Glen Walters
1414 El Camino Real
San Carlos, California
M/F Contract AF33(038)-30525

Dorne & Margolin
30 Sylvester Street
Westbury
Long Island, New York
M/F Contract AF33(616)-2037

Douglas Aircraft Company, Inc.
Long Beach Plant
Attn: J.C. Buckwalter
Long Beach 1, California
M/F Contract AF33(600)-25669

Electronics Research, Inc.
2300 N. New York Avenue
P.O. Box 327
Evansville 4, Indiana
M/F Contract AF33(616)-2113

DISTRIBUTION LIST (Cont)

Beech Aircraft Corporation
Attn: Chief Engineer
6600 E. Central Avenue
Wichita 1, Kansas
M/F Contract AF33(600)-20910

Bell Aircraft Corporation
Attn: Mr. J.D. Shantz
Buffalo 5, New York
M/F Contract W-33(038)-14169

Boeing Airplane Company
Attn: G.L. Hollingsworth
7755 Marginal Way
Seattle, Washington
M/F Contract AF33(038)-21096

Grumman Aircraft Engineering Corp.
Attn: J.S. Erickson,
Chief Electronics Engineer
Bethpage
Long Island, New York
M/F Contract NOa(s) 51-118

Hallicrafters Corporation
Attn: Norman Foot
440 W. 5th Avenue
Chicago, Illinois
M/F Contract AF33(600)-26117

Hoffman Laboratories, Inc.
Mr. S. Varian
Los Angeles, California
M/F Contract AF33(600)-17529

Hughes Aircraft Corporation
Division of Hughes Tool Company
Attn: Dr. Vanatta
Florence Avenue at Teale
Culver City, California
M/F Contract AF33(600)-27615

Johns Hopkins University
Radiation Laboratory
Attn: Dr. D.D. King
1315 St. Paul Street
Baltimore 2, Maryland
M/F Contract AF33(616)-68

Fairchild Engine & Airplane Corp.
Fairchild Airplane Division
Attn: L. Fahnestock
Hagerstown, Maryland
M/F Contract AF33(038)-18499

Federal Telecommunications Lab.
Attn: Mr. A. Kandoian
500 Washington Avenue
Nutley 10, New Jersey
M/F Contract AF33(038)-13289

Glenn L. Martin Company
Baltimore 3, Maryland
M/F Contract AF33(600)-21703

Massachusetts Institute of Tech.
Attn: Prof. H.J. Zimmerman
Research Lab. of Electronics
Cambridge, Massachusetts
M/F Contract AF33(616)-2107

North American Aviation, Inc.
Aerophysics Laboratory
Attn: Dr. J.A. Marsh
12214 Lakewood Boulevard
Downey, California
M/F Contract AF33(038)-18319

North American Aviation, Inc.
Los Angeles International Airport
Attn. Mr. Dave Mason
Engineering Data Section
Los Angeles 45, California
M/F Contract AF33(038)-18319

Northrop Aircraft Incorporated
Attn: Northrop Library
Dept 2135
Hawthorne, California
M/F Contract AF33(600)-22313

Ohio State Univ. Research Foundation
Attn: Dr. T.C. Tice
310 Administration Bldg.
Ohio State University
Columbus 10, Ohio
M/F Contract AF18(600)-85

DISTRIBUTION LIST (Cont.)

Land-Air Incorporated
Cheyenne Division
Attn: Mr. R.J. Klessig
Chief Engineer
Cheyenne, Wyoming
M/F Contract AF33(600)-22964

Lockheed Aircraft Corporation
Attn: C.L. Johnson
P.O Box 55
Burbank, California
M/F NOa(S)-52-763

McDonnell Aircraft Corporation
Attn: Engineering Library
Lambert Municipal Airport
St. Louis 21, Missouri
M/F Contract AF33(600)-8743

Michigan, University of
Aeronautical Research Center
Attn: Dr. R.D. O'Neill
Willow Run Airport
Ypsilanti, Michigan

Chief
Bureau of Ordnance
Department of the Navy
Attn: A.D Bartelt
Washington 25, D.C.

Farnsworth Electronics Co.
3700 Pontiac Avenue
Ft. Wayne, Indiana
Attn: Tech. Librarian

Republic Aviation Corporation
Attn: Mr. Thatcher
Hicksville, Long Island, New York
M/F Contract AF18(600)-1602

Director, National Security Agency
RADE 1 GM, Attn: Lt. Manning
Washington 25, D.C.

Stanford Research Institute
Menlo Park, California
Attn: Mr. J.T. Bolljahn
M/F Contract Af33(600)-25669

Radioplane Company
Van Nuys, California
M/F Contract AF33(600)-23893

Raytheon Manufacturing Company
Attn: Alice G. Anderson, Librarian
Wayland Laboratory
Wayland, Massachusetts

Republic Aviation Corporation
Attn: Engineering Library
Farmingdale
Long Island, New York
M/F Contract AF33(038)-14810

Ryan Aeronautical Company
Lindbergh Drive
San Diego 12, California
M/F Contract W-33(038)-ac-21370

Sperry Gyroscope Company
Attn: Mr. B. Berkowitz
Great Neck
Long Island, New York
M/F Contract AF33(038)-14524

Temco Aircraft Corp
Attn: Antenna Design Group
Dallas, Texas
M/F Contract AF33(600)-31714

North American Aviation, Inc.
4300 E. Fifth Avenue
Columbus, Ohio
Attn: Mr. James Leonard
M/F Contract AF33(038)-18319

General Electric Co.
French Road
Utica, New York
Attn: Mr. Grimm, LMEED
M/F Contract AF33(600)-30632

Westinghouse Electric Corporation
Post Office Box 746
Baltimore 3, Maryland
Attn: Mr. R.C. Digilio

AF33(616)-3220 UNCLASSIFIED REPORTS ONLY

Prof. J.R. Whinnery
Dept. of Electrical Engineering
University of California
Berkeley, California

Professor Morris Kline
Mathematics Research Group
New York University
45 Astor Place
New York, N.Y.

Prof. A.A. Oliner
Microwave Research Institute
Polytechnic Institute of Brooklyn
55 Johnson Street - 3rd Floor
Brooklyn 1, New York

Dr. C.H. Papas
Dept. of Electrical Engineering
California Institute of Technology
Pasadena, California

Radio Corporation of America
R.C.A. Laboratories Division
Princeton, New Jersey

Attn: Librarian

Electrical Engineering Res. Lab.
University of Texas
Box 8026, University Station
Austin, Texas

Exchange and Gift Division
The Library of Congress
Washington 25, D.C.

Dr. Robert Hansen
8356 Chase Avenue
Los Angeles 45, California

Technical Library
Bell Telephone Laboratories
463 West Street
New York 14, New York

Dr. R.E. Beam
Microwave Laboratory
Northwestern University
Evanston, Illinois

Department of Electrical Engineering
Cornell University
Ithaca, New York

Attn: Dr. H.G. Booker

Applied Physics Laboratory
Johns Hopkins University
8621 Georgia Avenue
Silver Spring, Maryland

Armed Services Technical Information Agency
Document Service Center
Knott Building
Dayton 2, Ohio 5 copies

Ennis Kuhlman
c/o Mc Donnell Aircraft
Lambert Municipal Airport
St. Louis 21, Missouri

Technical Reports Collection
303 A Pierce Hall
Harvard University
Cambridge 38, Massachusetts

Attn; Mrs. M.L. Cox, Librarian

Physical Science Laboratory
New Mexico College of A & MA
State College, New Mexico

Attn: R. Dressel

K.S. Kelleher
Melpar, Inc.
3000 Arlington Blvd.
Falls Church, Virginia

Electronics Research Laboratory
Stanford University
Stanford, California

Attn: Dr. F. E. Terman